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Development of a Design Guideline for Pile Foundations Subjected to Liquefaction-Induced Lateral Spreading

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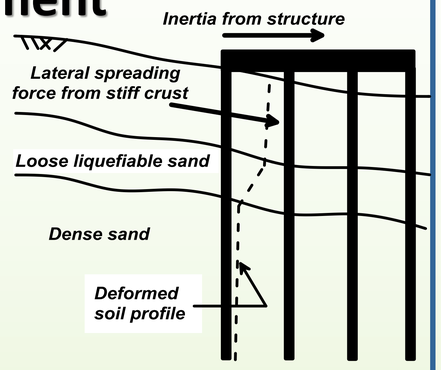
PSU GEOTECHNICAL ENGINEERING

Problem Statement



Past earthquakes confirmed that seismically-induced kinematic loads from soil lateral spreading and inertial loads from structure can cause severe damages to pile foundations. The research questions are:

- How to combine inertial and kinematic loads in design of pile foundations in liquefied soil?
- How the combination of inertia and kinematics changes with depth?
- How this combination is affected by long-duration earthquakes?
- How this combination affects inelastic demands in piles?

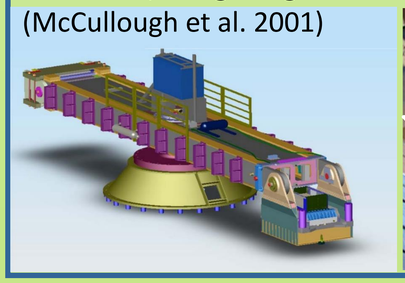
Background

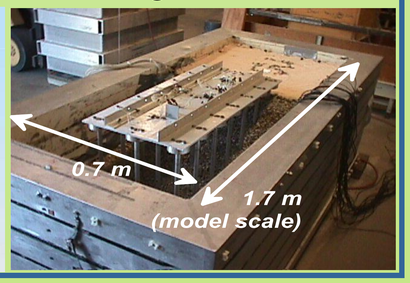
Current design codes provide varying recommendations on the combination of inertia and kinematics.

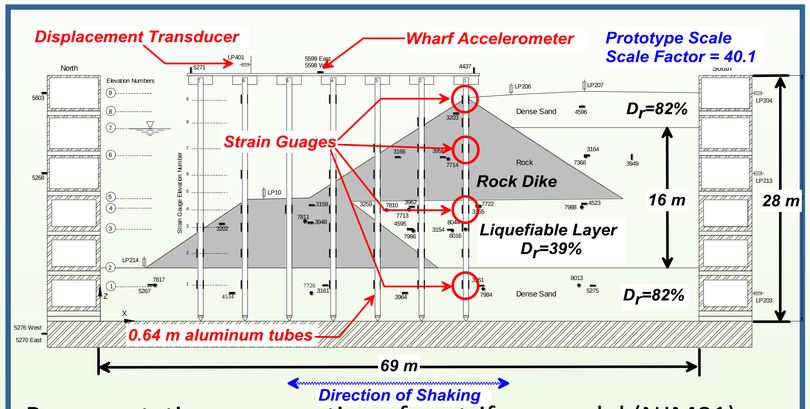
Design Code	Kinematic	Inertial
MCEER/ATC (2003)	▪ Independent inertia and kinematics ▪ I&K may interact during long-duration shakings	
Caltrans (2012) ODOT(Ashford et al. 2012)	100%	50%
WSDOT (2015)	100%	25%
AASHTO (2014)	▪ simultaneous effects only for M>8	
ASCE/ COPRI 61-14	▪ Independent effects of I&K ▪ evaluate this assumption on a project-specific basis	
ASCE 7-16 (NEHRP 2015 Provisions)	▪ do not require combining I&K	
Tokimatsu et al. (2005), Architectural Institute of Japan (2001)	▪ In-phase and out-of-phase I&K based on natural period of superstructure and ground	
Cubrinovski et al. (2014)	▪ a portion of inertia may be combined with kinematics at the discretion of the engineer	

Centrifuge Model

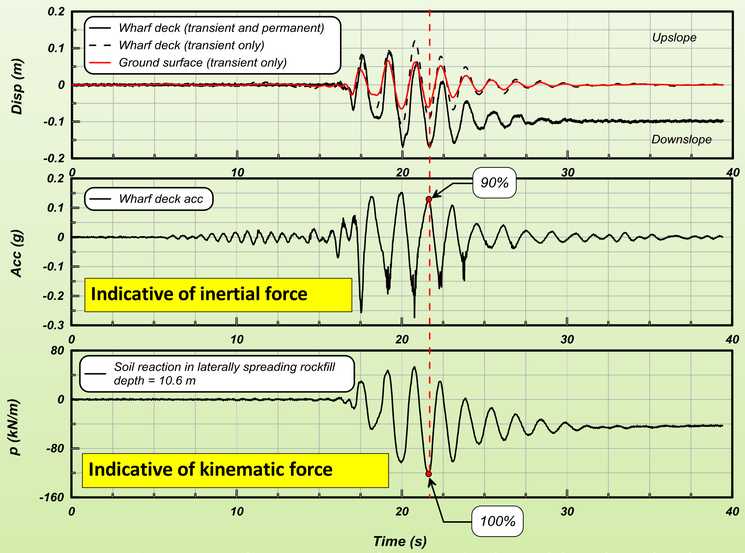
Five centrifuge tests were performed on pile-supported wharves in liquefied soils by Dickenson, McCullough and Schlechter, using the geotechnical centrifuge at UC Davis. (McCullough et al. 2001)







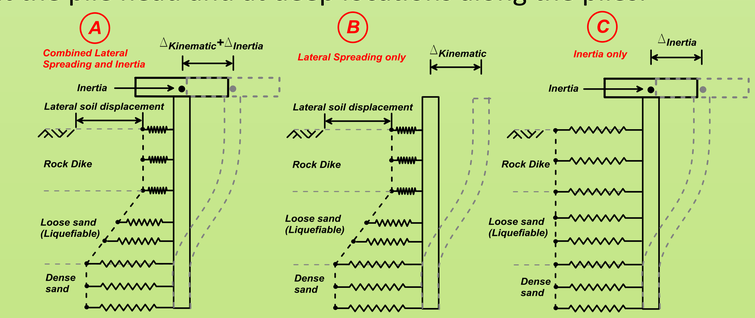
Representative cross section of centrifuge model (NJM01)



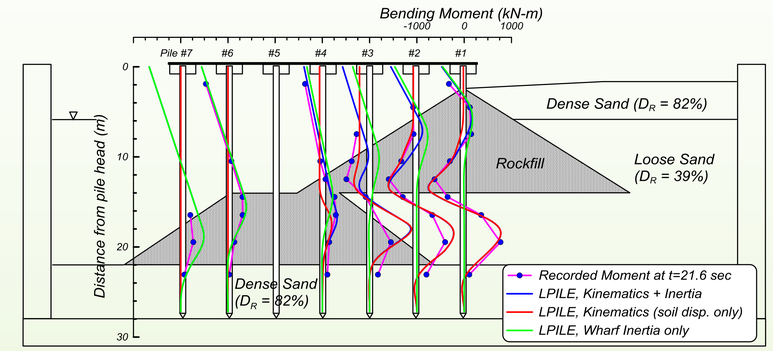
Representative time histories of recorded and back calculated data showed that both inertia and kinematic are close to 100%.

Pseudo-static Analysis

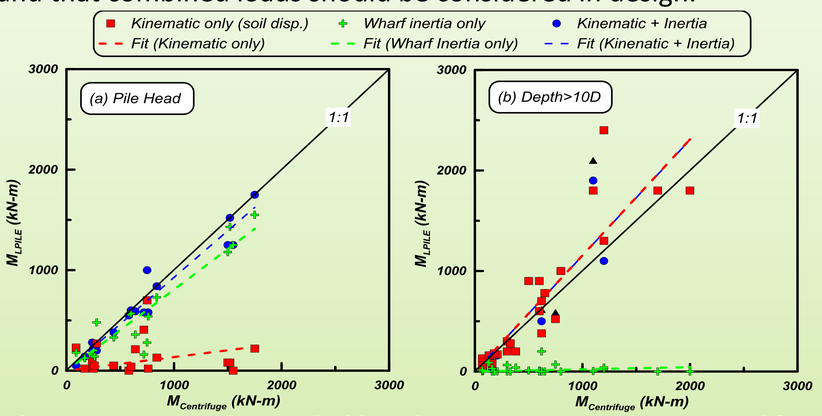
The p-y models performed in LPILE were subjected to three loading conditions to investigate the various load combinations in estimating the large bending moments that developed at the pile head and at deep locations along the piles.



Interaction of Inertia and Kinematic



Inertia and kinematic fully interact at pile head and shallow depths, and that combined loads should be considered in design.



The comparison of recorded bending moments and estimated from LPILE in all five centrifuge tests, proposed below load combinations to estimate bending moments at different depths

Location of maximum bending moment	Proposed load combination to be considered in design
Pile head	100% Kinematics + 100% Inertia
Deep locations (>10D)	100% Kinematics + 0% Inertia

Future Works

- Perform numerical analysis in FLAC2D and validate against centrifuge data
- Evaluate the effects of long duration earthquakes and piles inelasticity on the combination of inertial and kinematic demands
- Propose design guidelines for piles in liquefied soils

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